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THESIS

ARTILLERY OBSERVER ERRORS IN FLASHING HIGH
BURST REGISTRATIONS WITH THE M2 AIMING CIRCLE

by

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June 1970

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ABSTRACT

This thesis is addressed to the problem of determining the magnitude and direction of artillery observer errors in flashing high burst registrations with the M2 aiming circle. The task of flashing high burst registrations was simulated by using neon lamps to represent the visual stimulus presented by an exploding artillery round. Nineteen field artillery officers were used as subjects in an experiment conducted to collect the necessary information. It wa found that larger errors were committed for measurements made in the vertical direction than for those in the horizontal direction. Most accurate measurements were made for flashes appearing in the first quadrant of the aiming circle reticle and for those appearing near the center of the reticle.

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I. INTRODUCTION AND OUTLINE

The high burst registration is one of two standard registration techniques now in use by the field artillery of the U. S. Army and Marine Corps. The procedure has been in use for many years and is accepted as a reliable technique for determining firing corrections necessary for delivery of accurate artillery fire. All registration techniques require a high degree of accuracy on the part of the gun crews and forward observers. However, the high burst procedure is particularly demanding of the observers since it requires human observers to make accurate measurements to bursts appearing at random locations in the observer's field of view. The duration of the visual stimulus presented by the burst is estimated to be as little as 0.1 seconds under some conditions.[1] The accuracy achieved in localizing these bursts is a key factor in determining the validity of the firing corrections derived from the high burst registration. To the best of the author's knowledge, this accuracy has never been measured directly.

This thesis is addressed to the problem of determining the magnitude and direction of artillery observer errors in localizing flashes when using the M2 aiming circle as an observation device. These errors were determined by

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[1] This is the author's estimate. The method used to arrive at this estimate is discussed in Section IV.

conducting an experiment simulating the actual conditions of flashing rounds as nearly as possible.[2] The experiment was intended to simulate the task of flash localization under night-time conditions. Although it was not the author's intention to devise optimal techniques for flashing high burst registrations, some analysis of the experimental data was made to establish indications of procedures which might improve the accuracy of the registration technique.

Apparently an accurate short-distance simulation of the flash localization task as it applies to the high burst registration has never been attempted before. Consequently, a large portion of the author's research and study for this paper was devoted to the task of devising an adequate simulation. The premise that the flash localization task can be accurately simulated is fundamental to the development of this study.

Section II contains a brief discussion of field artillery registrations with emphasis on the high burst procedure. The M2 aiming circle, the observation instrument used in the experiment, is described in Section III. The reader who is familiar with these subjects may want to omit

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[2]The observer's task which is of interest here is sometimes referred to as "flash localization" in the literature. In artillery terminology, this task is often called "flashing the rounds, or bursts" or simply "flashing." The visual stimulus created by an exploding artillery round is usually called "the burst" or "flash."

these two Sections. On the other hand, the reader who has little knowledge of field artillery may find it helpful in understanding the terminology used in those Sections and elsewhere in this paper to refer to the Dictionary of United States Military Terms for Joint Usage [Ref. 1].

The flash simulation apparatus designed specifically for the experiment and the subjects used are discussed in Section IV. Section V contains a discussion of the experimental procedure. The findings and a discussion thereof are contained in Sections VI and VII respectively. Conclusions and recommendations are presented in Section VIII.

Appendix A is a sketch of the electrical circuit used for flash simulation. Appendix B contains a complete listing of the experimental observations and computed means and standard deviations of the observations.

II. FIELD ARTILLERY REGISTRATIONS

A. PURPOSE OF REGISTRATIONS

Standard firing tables have been devised for each type of field artillery weapon by firing a large number of projectiles from weapons under standard material and atmospheric conditions. Hence under these standard conditions, a projectile fired from a cannon will impact at a point that can be predicted with near perfection, allowing for known variability. Of course these standard conditions are almost never realized when firing is conducted under training or combat situations. Consequently, registration procedures have been developed which permit the identification of errors caused by firing under these nonstandard conditions, as well as those resulting from small errors in survey and the plotting of firing charts. Field Manual 6-40 [Ref. 2], the basic manual for field artillery gunnery, describes the purpose of registrations as follows: "... to determine the firing data (called adjusted data) that will place the mean burst location of rounds fired with that data at a point of known location. Registration data is used to determine corrections which, when applied, will compensate for the cumulative errors contained in survey, the firing chart, material, and nonstandard atmospheric conditions." Component corrections are always computed for range and deflection. If time fuze is to be used, fuze corrections must also be computed.

B. REGISTRATION PROCEDURES COMMONLY USED

There are only two standard registration procedures prescribed for use by the U. S. Army and Marine Corps. They are the precision registration procedure and the high burst/mean-point-of-impact procedure. Under combat situations, ad hoc procedures are occasionally used to conserve time and ammunition or in an attempt to achieve an exceptionally high degree of accuracy. Such procedures are not of interest here and will not be discussed.

1. The Precision Registration

The theoretical basis for this procedure is the assumption that rounds fired from a cannon with fixed settings of elevation and deflection impact according to a bivariate normal distribution. The parameters of this distribution are known, for practical purposes, for all permissible settings on the cannon. Under the precision registration procedure, a sampling technique is used to estimate the elevation and deflecting settings required to make the center of the impact pattern coincident with a known point.

Only one cannon from the firing unit is used to conduct the firing. This cannon is called the "base piece." Its location must be accurately established by survey. The location of a suitable target, called the "registration point," must be similarly established. The registration point must be near the center of the sector into which the unit is required to deliver fire. Additionally, it must

be permanent or semipermanent in nature, easily identifiable, and clearly visible to at least one forward observer. The forward observer is normally equipped with four-power or seven-power binoculars for use in making observations.

The registration point is fired on using the base piece. Adjustments are made to the firing data based on the forward observer's judgement of the point-of-impact of each round in relation to the registration point. Firing is continued in this manner with progressively smaller changes being made to the firing data. Firing is stopped when small changes -or no changes- in the firing data result in rounds impacting on all sides of the registration point. The adjusted elevation and deflection settings are then computed.

It has been the author's experience that about 12 rounds of ammunition must be expended to determine the adjusted elevation and deflection settings. If time fuze corrections are required, at least six additional rounds must be fired. Hence a total of 18 or 20 rounds may be required to obtain adjusted data using the precision registration procedure.

2. <u>The High Burst/Mean-Point-of-Impact Procedure</u>

The high burst and mean-point-of-impact techniques are nearly identical and hence are considered to be a single registration procedure. They differ only in that time fuze is used in the high burst technique and rounds are required to burst above ground level. Registration corrections for elevation, deflection and time fuze can be

determined simultaneously. In the mean-point-of-impact procedure, point-detonating fuze is used and hence time fuze corrections cannot be determined. Only the high burst technique is discussed here.

With this technique, a sampling procedure is used to estimate the mean burst point of a number of rounds fired with fixed elevation, deflection and time fuze settings. Firing data is calculated which causes rounds to burst approximately 50 meters above ground level, near the center of the sector into which the unit must deliver fire. Rounds are fired by the base piece only. Measurements are taken to each burst from each of two or more observation posts. These measurements are used with a method of intersection to estimate the mean burst point of all rounds fired with these fixed settings. Rounds are fired in this manner until measurements from six useable rounds are obtained. A round is considered useable if it does not seem to be erratic as determined by the fire direction officer. The determination of whether a round is erratic is based principally upon the measurements reported by the observation posts.

The location of the base piece and all observation posts must be established by survey. Additionally, each of these positions must be connected by survey to establish a common directional reference. Each observation post must be manned and equipped with some type of azimuth measuring device, normally an optical instrument.

Before firing commences, orienting data is provided each observation post to increase the likelihood that the first burst will appear within the field of view of each observation instrument. The initial round fired is used by each observer to improve the instrument orientation. Present procedure dictates that the instrument be oriented so that the center of the reticle is coincident with the point at which the orienting burst appeared. The azimuth and verticle angle settings on each instrument are then recorded. All subsequent measurements are reported as deviations from these recorded readings and the observer does not normally reorient the instrument during the conduct of the registration.

For each subsequent round fired, each observation post reports the horizontal deviation to the nearest mil. Only the observation post whose location is established with the least amount of survey field work reports the vertical deviation. All measurements are reported as left, right, up or down from the center of the reticle.

The command "SHOT" is used to notify the observers that a round has been fired. Approximately five seconds before the round is expected to detonate, the command "SPLASH" is given. This assures that the observer is always adequately alerted to the fact that a measurement must be made.

The visual stimulus presented to the observer by a detonating artillery round varies with light and atmospheric

conditions and with the size of the shell fired. During daylight hours, the observer may sight on the small cloud of smoke created by the explosion. The smoke cloud may remain visible for several seconds. However, during the hours of darkness or when visibility is otherwise reduced, only the flash of light created by the explosion is visible. The duration of this flash is quite short.

The high burst registration is generally preferred to the precision registration during periods of poor visibility or when a readily identifiable registration point is not available. The relatively sophisticated survey requirements of the high burst procedure make it less preferred than the precision registration technique when time is a critical factor.

A detailed discussion of both the precision and high burst registration procedures is contained in Chapter 19, Field Manual 6-40 [Ref. 2].

III. THE M2 AIMING CIRCLE

The M2 aiming circle is a lightweight instrument possessing many of the characteristics of a surveyor's transit. It is used to measure the azimuth and elevation angles of a ground or aerial target with respect to a preselected reference line or point. The instrument is equipped with a four-power, fixed-focus telescope with a field of view of ten degrees. The reticle of the telescope consists of a pair of crosslines graduated to give angular readings from zero to 85 mils, in increments of five mils. Figure 1 is a sketch of the telescope reticle. A self-contained lighting device is provided for illuminating the reticle. This device is powered by two standard flashlight batteries and is equipped with a rheostat to permit the observer to control the degree of reticle illumination. A detailed description of the M2 aiming circle is contained in Section II, Chapter 1, Technical Manual 9-6166 [Ref. 3].

The aiming circle is used for a variety of purposes in field artillery work. Flashing high burst registrations is merely one of these. It should be noted that this instrument is not the only type available for flashing high burst registrations. It was selected for use in the experiment conducted by the author because it <u>is</u> frequently used for this purpose and because the simplicity of its telescope design makes it adaptable for use at extremely short distances.

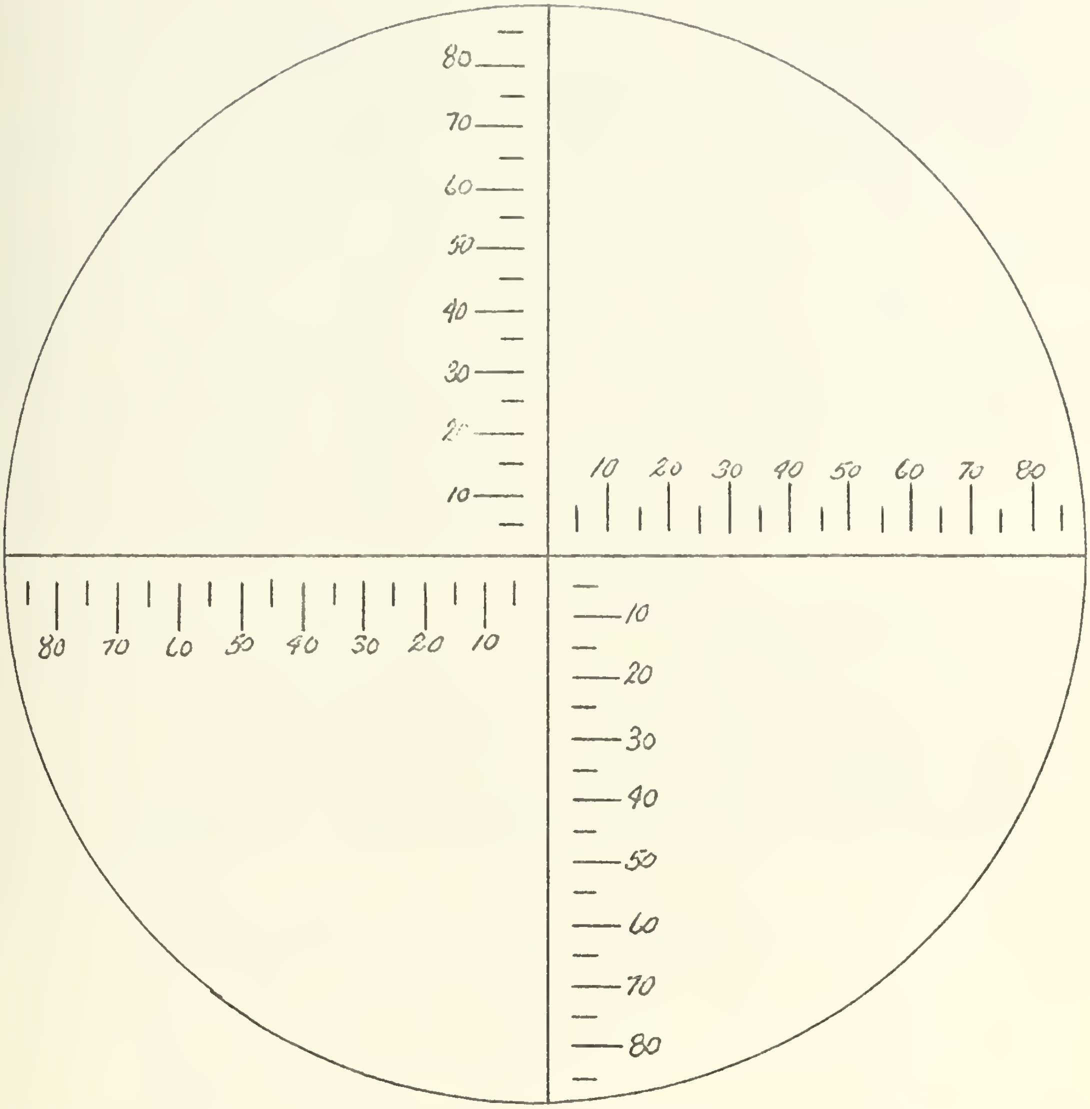

Figure 1. Telescope reticle of M2 aiming circle

IV. EXPERIMENTAL APPARATUS AND SUBJECTS

A. FLASH SIMULATION

It is believed that an adequate simulation of the flash created by an exploding artillery round must approximate the following visual characteristics of the flash: size, duration, light intensity, rise time of the light, and color. Major difficulties were encountered in attempting to identify these characteristics for various types of artillery rounds. The results of an extensive search of published technical reports and answers to direct queries to appropriate agencies of the Army, Navy and Marine Corps convinced the author that these visual characteristics are not known. However, the following useful estimates for the 155 millimeter high explosive artillery shell were obtained [Ref. 4]:

Diameter of the flash: 12 feet

Rise time of the light: 0.1 Milliseconds

Color: Orange

Estimates between 0.1 and 0.2 seconds for the flash duration were provided by various personnel within the Department of the Army through informal discussions.

These estimates were used to devise an initial simulation using an electrical circui to set off an NE-48 neon lamp. This initial simulation was observed by two field artillery officers chosen because of their extensive experience in flash observation. Several revisions of the

simulation were made based on the subjective judgement of these officers.

A sketch of the resulting circuit, as used for the simulation, is presented in Appendix A. The characteristics of the flash resulting from the simulation were:

Rise time of the light: 1.0 milliseconds

Flash duration: 0.1 seconds

Light intensity: 1.88 candlepower

Color: Orange

The flash from the neon lamp was masked to a diameter of two centimeters for the experiment. The simulation viewed from ten meters is believed to correspond approximately to viewing an exploding 155 millimeter shell from a distance of 2000 meters under night-time conditions.

It is unrealistic to believe that all the visual characteristics of the actual flash were duplicated by the simulation. However, the diameter of the flash was approximated very accurately by masking. The rise time of the light is so short for both the estimate and the simulation that it is believed that the small difference between the estimate and the simulation is negligible.

Due to the lack of information concerning the actual flash, it is impossible to determine what effect, if any, the inaccuracies in the simulated light intensity and flash duration might have on the experimental data. However, there is reason to believe that the effect is negligible. Leibowitz et al. found that accuracy for flash localization

in the radial dimension is independent of flash intensity and duration for durations in the range of 0.01 to 0.64 seconds [Ref. 5]. A study by Easley and Jackson to determine if accuracy is independent of flash duration for localizations made in two dimensions was inconclusive [Ref. 6].

B. FLASH PRESENTATION BOARD

Flashes were simulated by using the electrical circuit discussed above to set off NE-48 neon lamps mounted on a flash presentation board.

The flash presentation board consisted of a 1/16th inch aluminum plate into which a matrix of 24 holes of two centimeter diameter were punched. Lamps were mounted on the back of the plate so that one was centered on each of the 24 holes. A white muslin sheet was stretched over the front of the board to achieve a circular flash and to prevent the subject from seeing the lamp directly.

The board was constructed for simulation when viewed at a distance of ten meters. At this distance, one centimeter on the board represents one mil from the observer's point of view.

The board was placed ten meters from the M2 aiming circle and oriented perpendicular to the line of sight. Reference lines drawn on the board at a distance of 30 centimeters from its center in each of the horizontal and

vertical directions were used in aligning the board to the reticle of the aiming circle.

The 24 flash positions superimposed on the reticle of the aiming circle are shown in Figure 2. The flash locations include only a small area of the total reticle. However, this area corresponds to a circular field of view of 85 meters in diameter at a distance of 2000 meters. It is believed that a large percentage of flashes would appear within this area for a high burst registration observed with this instrument from that distance.

C. SUBJECTS

Nineteen subjects were used in the experiment. Each was a field artillery officer of the U. S. Army or Marine Corps. All subjects were qualified observers in the sense that each had performed the task of flashing high burst registrations under combat or training conditions and considered himself fully qualified in the procedure.

The average age of the subjects was 31.3 years. All subjects had 20/20 vision, or vision correctable to 20/20.

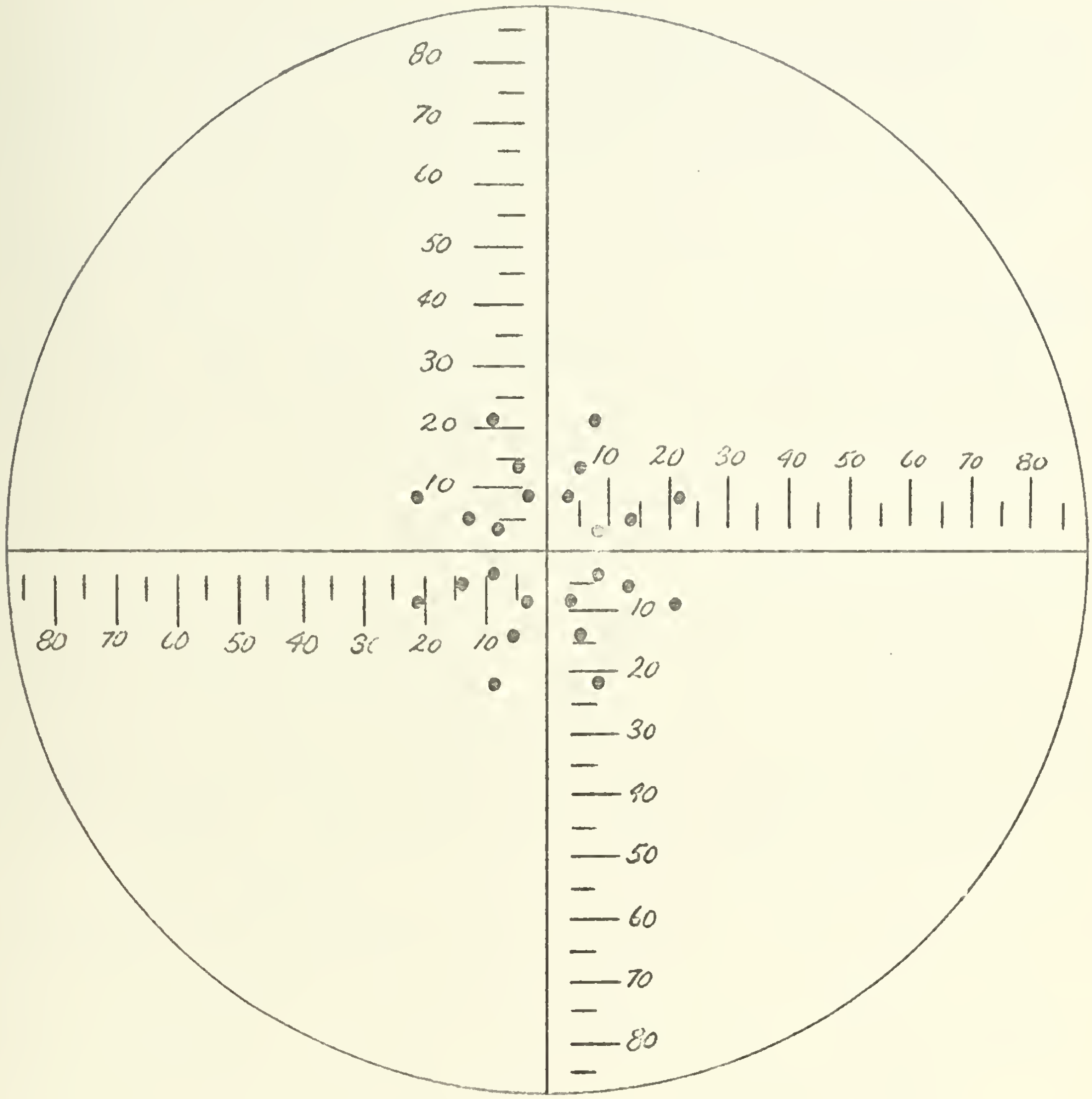

Figure 2. Telescope reticle of the M2 aiming circle with flash locations superimposed

V. EXPERIMENTAL PROCEDURE

Each of the 19 subjects was required to localize each of the 24 flashes on the presentation board. The sequence of flash presentations was completely randomized. Each subject was assigned a different sequence.

The experiment was conducted in a completely blacked-out room. When observing through the telescope of the aiming circle, the subject's visual field was completely empty except for the illuminated reticle of the scope. Each subject was dark adapted for ten minutes. Four practice flashes were presented to familiarize the subject with the experimental procedure. These were the sixth, tenth, fourteenth, and eighteenth flashes of the sequence assigned to the subject. These flashes were presented again in their normal sequence during the recorded portion of the experiment. The subject was permitted to determine the speed at which the experiment progressed. Subjects were permitted rest breaks as desired. No flashes were presented until the subject reported "READY." The experimenter gave the command "SPLASH" approximately five seconds before presenting each flash. Subjects reported both horizontal and vertical measurements for each flash as "RIGHT (LEFT) <u>horizontal measurement</u> UP (DOWN) <u>vertical measurement</u>." The average time required by the subjects in localizing the 24 flashes, including rest breaks, was ten minutes, 23 seconds. Subjects were given no information

concerning the accuracy of their measurements during the conduct of the experiment.

Subjects were asked to comment on the realism of the simulation after the experiment was completed.

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VI. FINDINGS

A. GENERAL ANALYSIS PROCEDURE

Errors in the horizontal and vertical directions were analyzed separately. For simplicity, these two directions are designated the X and Y directions, respectively.

Errors resulting from reported deviations from reticle center in excess of the actual deviation of the flash were considered to be positive in sign. These are errors of over-estimation. Errors of underestimation were considered to be negative in sign. This convention is mathematically convenient and tends to compensate for any small errors in alignment of the flash presentation board with the telescope reticle when errors are averaged over all flash locations.

The analysis of variance is one of the techniques used in analyzing the experimental data. The model for a completely randomized design with subsampling [Ref. 7] was used for each analysis of variance.

Appendix B contains a listing of the location of each flash used in the experiment, the observations from the experiment, and the sample mean and variance of errors for each flash location.

B. COMPARISON OF X AND Y ERRORS

The sample mean and standard deviation for the X and Y errors over all flash locations are contained in Table 1.

TABLE 1

X AND Y ERRORS OVER ALL FLASH LOCATIONS

Component Error	Mean	Standard Deviation
X	-0.09	1.69
Y	0.80	1.67

The product moment correlation coefficient of X and Y components of each measurement error was computed. The value of the coefficient was 0.0416. Errors in the X and Y direction were essentially uncorrelated.

Separate *t* statistics were computed to determine if mean errors in the X and Y direction were different from zero. The value of the statistic for errors in the X direction was -1.12, with 455 degrees of freedom. The probability associated with this value of the statistic is less than 0.50 and greater than 0.20. The value of the *t* statistic for errors in the Y direction was 10.0. The probability associated with this value of the statistic is less than 0.001. The X component errors did not vary from an hypothesized mean of zero, whereas the Y errors did with high confidence.

An F statistic equal to 1.02 was calculated to test for equality of variances of errors in the X and Y directions. The probability associated with this value of the F statistic is greater than 0.999. An hypothesis of equality of variance in the X and Y directions was accepted.

A t statistic for independent samples with equal variances was computed to test for equality of the mean errors in each of the two directions. The resulting value was -8.07. There were 910 degrees of freedom. The probability associated with this value of the statistic is less than 0.0005. The mean for Y errors was larger than that for X errors with high confidence.

C. ANALYSIS OF ERRORS BY QUADRANT

Data was grouped to permit a comparison of relative accuracy of flash localization as a function of the quadrant of the reticle within which the flash appeared. Quadrants were numbered clockwise, beginning with the upper-right quadrant. Table 2 contains the sample means and standard deviations of the component errors by quadrant.

TABLE 2

X AND Y ERRORS BY QUADRANT

Component Error	Quadrant	Mean	Standard Deviation
X	1	0.08	1.74
X	2	0.28	1.80
X	3	-0.39	1.47
X	4	-0.36	1.64
Y	1	0.32	1.41
Y	2	1.18	1.73
Y	3	1.25	1.91
Y	4	0.46	1.38

An analysis of variance was conducted to test for equality of mean errors in the X direction for the four quadrants. The resulting analysis of variance table is shown in Table 3.

TABLE 3

ANALYSIS OF VARIANCE TABLE FOR X ERRORS BY QUADRANT

Source	Sum of Squares	DF	Mean Square	F Ratio
Quadrants	37.5413	3	12.5137	1.8316
Experimental Error	491.9080	72	6.8320	
Sampling Error	765.4559	380		
Total	1294.9052	455		

The probability associated with the computed F statistic is greater than 0.10 and less than 0.25. There is an indication that the mean of the X errors was not equal for all quadrants, with smallest mean error occurring in the first quadrants.

An analysis of variance was also conducted to test for equality of mean errors in the Y direction for the four quadrants. The resulting analysis of variance table is shown in Table 4. The probability associated with the computed value is less than 0.001. Pairwise comparisons

TABLE 4

ANALYSIS OF VARIANCE TABLE FOR Y ERRORS BY QUADRANT

Source	Sum of Squares	DF	Mean Square	F Ratio
Quadrants	78.7939	3	26.2646	6.1878
Experimental Error	305.6123	72	4.2446	
Sampling Error	885.3504	380		
Total	1269.7566	455		

using Tukey's method [Ref. 8] and a significance level of 0.05 reveal that

$$\mu_{Y_1} = \mu_{Y_4} < \mu_{Y_2} = \mu_{Y_3},$$

where μ_{Y_i} denotes the mean of the errors in the Y direction for the i^{th} quadrant. The mean of the Y errors in the first and fourth quadrants was significantly smaller than the mean of the Y errors in the second and third quadrants. However, the mean was essentially equal in the first and fourth quadrants and in the second and third quadrants.

D. ERRORS AS A FUNCTION OF DISTANCE OF FLASH FROM RETICLE CENTER

Data was grouped for all flash points located at a constant distance from the center of the reticle. There were three such groups, each containing data from eight flash points located at distances of 8.5, 13.9 or 22.5

centimeters from the center of the flash presentation board. These three groups were numbered beginning with the group nearest the center of the reticle. Table 5 contains the sample means and standard deviations of the component errors by group.

TABLE 5

X AND Y ERRORS BY CIRCLE-GROUP

Component Error	Group	Mean	Standard Deviation
X	1	0.10	1.28
X	2	-0.03	1.61
X	3	-0.35	2.06
Y	1	0.51	1.33
Y	2	0.88	1.56
Y	3	1.01	2.02

An analysis of variance was conducted to test for equality of mean errors in the X direction among the three groups. The resulting analysis of variance table is shown in Table 6. The probability associated with the computed F ratio is greater than 0.10 and less than 0.25. There is an indication that the mean of the X errors differed increasingly from zero with increasing distance of the flash from reticle center.

The table resulting from an analysis of variance to test for equality of mean errors in the Y direction among

TABLE 6

ANALYSIS OF VARIANCE TABLE FOR X ERRORS BY CIRCLE-GROUP

Source	Sum of Squares	DF	Mean Square	F Ratio
Groups	16.7233	2	8.3616	1.7946
Experimental Error	251.6039	54	4.6593	
Sampling Error	1022.5632	399		
Total	1290.8904	455		

the three groups is displayed in Table 7. The probability associated with the computed F ratio is greater than 0.05 and less than 0.10. There is a strong indication that the mean of the Y errors increased with increasing distance of the flash from the center of the reticle.

TABLE 7

ANALYSIS OF VARIANCE TABLE FOR Y ERRORS BY CIRCLE-GROUP

Source	Sum of Squares	DF	Mean Square	F Ratio
Groups	20.2527	2	10.1263	2.5938
Experimental Error	210.8173	54	3.9040	
Sampling Error	1038.4651	399		
Total	1269.5351	455		

VII. DISCUSSION OF FINDINGS AND A DISTRIBUTION FUNCTION FOR RADIAL ERROR

A. INTERPRETATION OF THE FINDINGS

The findings clearly indicate that there exists a significant bias in measurements made in the Y direction, but there is none for measurements made in the X direction. On the average, observers tend to overestimate vertical deviation. Furthermore, the findings demonstrate that the variance of errors in the two directions are equal. The very small value of the product moment correlation coefficient implies that there is essentially no linear correlation between errors for the two directions for those flash locations used in the experiment.

The analysis of errors as a function of the quadrant in which the flash appears indicates that measurements in the X direction tend to be most accurate for flashes appearing in the first quadrant. There is a strong indication that measurements in the Y direction are most accurate for flashes appearing in the first and fourth quadrants. Hence best overall flash localization accuracy may be expected for flashes appearing in the first quadrant. This finding is in general agreement with the results of numerous studies reported in the literature which show that familiar words and figures tachistoscoptically presented to subjects fixating a central point in the visual field tend to be better recognized and perceived when presented in the right

visual field than when presented in the left [Ref. 9, 10, 11]. This tendency to perceive better when scanning from left-to-right may be a partial explanation for improved flash localization accuracy in the first quadrant. Of course this result did not hold for flashes presented in the second quadrant. This apparent inconsistency is perhaps attributable to the perceptual differences caused by the direction of vertical scanning, for the findings of this experiment indicate that better accuracy is achieved for measurements in the Y direction when scanning upward.

The analysis of errors as a function of the distance of the flash from the center of the reticle indicates that accuracy of flash localization deteriorates with increasing distance. Furthermore, accuracy of localization in the Y direction tends to be more sensitive to distance than does the accuracy for localization in the X direction. That accuracy decreases with increasing distance is not a surprising result, for it has been rather clearly demonstrated that visual perception and recognition under the general conditions of the experiment do deteriorate as distance increases [Ref. 10, 11, 12]. Kraemer observed this same result in evaluating the gunner's reticle of the M48 tank [Ref. 13]. This result is generally attributed to the increasing amount of eye movement required and to the increased demands on the observer's memory.

B. PRACTICAL CONSEQUENCES OF THE FINDINGS

The findings indicate that some adjustments to the present high burst registration might be made to improve the accuracy of the firing corrections derived through application of the procedure. The findings clearly indicate that measurements in the Y direction are no more reliable than those in the X direction. This casts some doubt on the wisdom of the present practice of using vertical measurements from only one observation post, for better estimates should result in the long run by using measurements from each observation post.

Knowledge of the nature of the errors committed in the flash localization task can be used to improve the estimate of the true location of the bursts over the long run. For instance, one approach might be to adjust the measurements reported by the observer based on the quadrant in which the flash appeared. Alternatively, adjustments could be made based on consideration of the distance of the flash's appearance from the center of the reticle.

A perhaps simpler procedure would be to orient the aiming circle so as to increase the likelihood that flashes will appear in the first quadrant. This can be achieved by orienting the center of the telescope reticle some distance to the left and below the point at which the orienting burst appears. Of course this procedure might result in increasing total eye movement in the flash localization task and this consequence should be considered in

devising an instrument orientation scheme. Consideration of the variability of the errors might also be made. Another possible consequence is the effect on accuracy which might result from the observer's knowledge of the fact that flashes are most likely to appear in the first quadrant. This effect, if any, was not investigated in the experiment.

C. DISTRIBUTION FUNCTION FOR RADIAL ERROR

The findings can be used to estimate the probability associated with particular values of the radial error of measurement.

Denoting the error in the horizontal measurement by X and that in the vertical measurement by Y, a distribution function for the radial error $R = \sqrt{X^2 + Y^2}$ can be derived under the following assumptions:

1. X and Y have a bivariate normal distribution
2. X and Y are independent
3. $\mu_X = \mu_Y = 0$
4. $\sigma = \sigma_X = \sigma_Y$

Under these assumptions, the joint density of X and Y is

$$f(X,Y) = \frac{1}{2\pi\sigma^2} e^{-\frac{X^2+Y^2}{2\sigma^2}} .$$

Transform to polar coordinates by setting

$$X = R\cos\theta, \; Y = R\sin\theta, \text{ where } \theta = \tan^{-1}\frac{Y}{X} .$$

Then

$$\Pr(R \leq r) = G(R) = \iint_A f(X,Y)\, dXdY = \iint_A f(R\cos\theta,\ R\sin\theta) R dR d\theta.$$

Let

$$g(R,\theta) = f(R\cos\theta,\ R\sin\theta)R = \frac{1}{2\pi\sigma^2}\ e^{-\frac{R^2}{2\sigma^2}}\ R.$$

Then

$$g(R) = \int_0^{2\pi} g(R,\theta)d\theta = \frac{R}{\sigma^2}\ e^{-\frac{R^2}{2\sigma^2}}, \qquad 0 < R < \infty.$$

Hence

$$\Pr(R \leq r_\circ) = \int_0^{r_\circ} g(R)dR = 1 - e^{-\frac{r_\circ^2}{2\sigma^2}}, \qquad 0 < R < \infty.$$

An estimate for σ can be determined from the sample standard deviations of X and Y computed for all flash locations. This gives the estimate $\frac{1.67 + 1.69}{2} = 1.68$.

Using this estimate for σ, the probability that a reported measurement is within one mil of the actual flash location is

$$\Pr(R \leq 1) = 1 - e^{-\frac{1}{5.64}} = 0.15.$$

Similarly, the probability that a measurement is within two mils of the actual flash location is

$$\Pr(R \leq 2) = 1 - e^{-\frac{4}{5.64}} = 0.51.$$

This distribution function was derived under the assumption that there is no bias in the component errors of estimate. However, the findings clearly show that there

is a significant bias for measurements in the Y direction. Hence the distribution function shown here can be expected to yield optimistic or highly generalized results.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The results of the experiment clearly demonstrate that when using the M2 aiming circle as an observation instrument, the accuracy of flash localization as it pertains to the high burst registration procedure is not independent of the location at which the flash appears on the reticle. In general, smallest errors result for flashes appearing in the first quadrant and for those appearing near the center of the reticle. These findings may be of practical significance in developing techniques of flash observation for the high burst registration when using the M2 aiming circle as an observation instrument.

The author's experience in conducting this study leads to the conclusion that the task of flash localization as it applies to the high burst registration can be accurately simulated. This conclusion is substantiated by the stated opinions of the 22 field artillery officers who observed the simulation devised by the author. Increased knowledge of the visual characteristics of exploding artillery rounds could be used to devise a more accurate simulation. It is the author's opinion that short distance simulations of the flash localization task can be of great value in training observers and conducting experimentation at very low material cost.

B. AREAS FOR FURTHER RESEARCH

Apparently no theoretical studies have ever been made of the comparative accuracy of the high burst and precision registration procedures. Such a study could be of value in evaluating proposed changes to these procedures. The accuracy of both of these procedures seems to depend heavily on reliable and accurate performance by the gun crews, observers and fire direction personnel. Studies of the errors committed by these personnel seem to be essential in making a realistic evaluation of the accuracy of the registration procedures. Of particular importance is the need for evaluating the accuracy with which forward observers are able to judge the relative locations of impacting rounds and a fixed target.

It is believed that the data obtained from the experiment conducted by the author can be of use in answering several questions relating to the high burst registration procedure. For instance, what are optimal locations for observation posts for flashing high burst registrations under combat conditions? What is the expected accuracy of the high burst registration procedure for various locations of the observation posts? What is the optimal number of observation posts to use under some suitable criteria? What are some rules of thumb which the fire direction officer can use in determining if a round is erratic? If more than two observation posts are used, how can one best

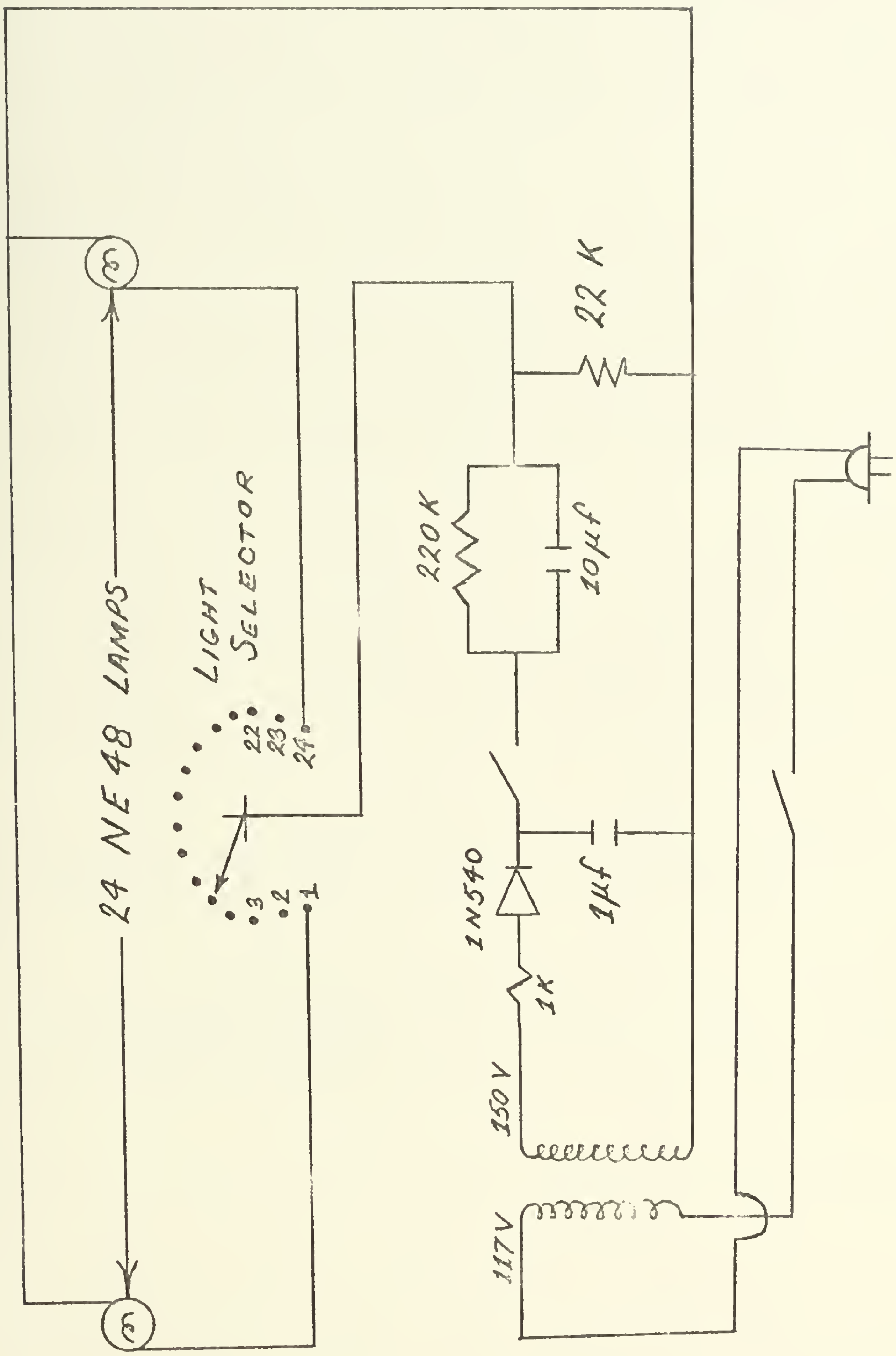
resolve the polygon of error that results when estimates from three or more observation posts do not coincide?

C. RECOMMENDATIONS

It is recommended that the Department of the Army consider taking steps to identify the visual characteristics of exploding artillery rounds under various light and atmospheric conditions. It is further recommended that consideration be given to developing short distance simulations of the flash localization task for use in training and experimentation.

APPENDIX A

ELECTRICAL CIRCUIT FOR FLASH SIMULATION



APPENDIX B

EXPERIMENTAL OBSERVATIONS AND MEANS AND STANDARD DEVIATIONS OF OBSERVATIONS

Flash Location	Component Error	Mean	Standard Deviation	Magnitude and Frequency of Errors Observed -6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7
R3, U8	X	0.79	1.03						2	5	8	3	1				
	Y	0.53	1.12						4	6	4	5					
R5,U13	X	-0.21	1.31				1	1	5	9	1	1	1				
	Y	0.68	1.25						3	6	6	3	1				
R8,U21	X	0.32	1.67					5	1	3	3	7					
	Y	0.42	2.39		1			3	4	1	3	3	2	2			
R8, U3	X	-0.26	1.24					2	7	7	1	1	1				
	Y	0.16	1.30					2	4	6	3	4					
R13,U5	X	0.05	2.22			1	2	1	5	1	4	2	2	1			
	Y	0.37	0.76					1		9	9						
R21,U8	X	-0.16	2.48	1		1	1	1	3	5	3	2	2				
	Y	-0.26	1.04					1	8	7	1	2					
L8, U3	X	-0.37	1.17				1	1	7	6	3	1					
	Y	0.63	1.21						4	3	10	1		1			
L13,U5	X	-0.37	2.00				3	2	5	4	2	2			1		
	Y	0.32	1.49				1		3	10		3	2				
L21,U8	X	-0.74	1.60			1	2	2	6	3	4	1					
	Y	1.26	1.37						1	5	6	4	1	2			
L3, U8	X	-0.05	1.51				1	2	5	4	3	4					
	Y	0.11	1.05						5	10	2	1	1				
L5,U13	X	0.42	1.74				1	1	2	9	1	2	2	1			
	Y	0.42	1.35				1		3	6	4	5					
L8,U21	X	-1.05	1.51		1	2	3	5	6	2							
	Y	0.05	1.59				1		6	8	1	1	1	1			
R8, D3	X	0.00	1.41					1	6	9	1		1	1			
	Y	0.95	0.85						1	3	12	2	1				

Flash Location	Component Error	Mean	Standard Deviation	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7
				Magnitude and Frequency of Errors Observed													
R13,D5	X	-0.26	1.73				3	1	5	3	3	4					
	Y	0.58	1.57				1		3	6	3	5		1			
R21,D8	X	0.53	2.67		1	1			4	5	3		2	2	1		
	Y	1.79	1.55						2	3	2	3	8	1			
R3, D8	X	0.53	1.47					2	2	6	4	3	2				
	Y	0.95	1.43					1	1	6	4	5	1	1			
R5,D13	X	0.84	1.07						1	7	7	2	2				
	Y	1.95	2.17					1		4	4	4	2	1	2		1
R8,D21	X	0.05	1.98				1	1	8	4	1	2		1	1		
	Y	0.89	2.18				1	1	4	2	5	1	2	2	1		
L8, D3	X	-0.05	1.22				1	2	5	6	5						
	Y	0.37	1.95				1	2	5	2	3	3	2	1			
L13,D5	X	-0.16	1.21				1		7	6	3	2					
	Y	1.26	1.59					1	2	3	4	3	6				
L21,D8	X	-0.89	2.08		1		4	2	4	3	4			1			
	Y	1.16	1.71					2	3	1		10	3				
L3, D8	X	0.21	0.79					1	1	10	7						
	Y	0.42	1.39					1	4	7	5	1					
L5,D13	X	-0.53	0.96				1	2	4	11	1						
	Y	1.47	1.39					1	1	2	3	8	4				
L8,D21	X	-0.89	1.91			1	4	3	3	3	2	3					
	Y	2.79	2.39					5					1	11	1	1	
Overall	X	-0.09	1.69	1	3	5	29	36	103	135	76	42	16	7	2	1	
	Y	0.80	1.67				6	17	76	116	90	81	38	26	4	1	1

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13. ABSTRACT

This thesis is addressed to the problem of determining the magnitude and direction of artillery observer errors in flashing high burst registrations with the M2 aiming circle. The task of flashing high burst registrations was simulated by using neon lamps to represent the visual stimulus presented by an exploding artillery round. Nineteen field artillery officers were used as subjects in an experiment conducted to collect the necessary information. It was found that larger errors were committed for measurements made in the vertical direction than for those in the horizontal direction. Most accurate measurements were made for flashes appearing in the first quadrant of the aiming circle reticle and for those appearing near the center of the reticle.

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ARTILLERY REGISTRATION						
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VISUAL PERCEPTION						
ARTILLERY OBSERVER						
RETICLE						

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